ANTHRANILATE REPELLENCY TO STARLINGS: CHEMICAL CORRELATES AND SENSORY PERCEPTION

J. RUSSELL MASON,[1] U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Denver Wildlife Research Center, Denver, CO 80225-0266
MICHAEL A. ADAMS, Monell Chemical Senses Center, 3500 Market Street, Philadelphia, PA 19104-3308
LARRY CLARK, Monell Chemical Senses Center, 3500 Market Street, Philadelphia, PA 19104-3308

Abstract: We investigated the physicochemical and sensory bases of anthranilate repellency to European starlings (*Sturnus vulgaris*). Physicochemical parameters that control volatility were positively correlated with avoidance. Nasal trigeminal chemoreception and olfaction were important for sensory detection. Methyl, isobutyl, ethyl, and isobutyl methyl anthranilate are as aversive as dimethyl anthranilate (methyl-N-methyl anthranilate) (DMA).

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Bird depredations to agricultural commodities are common and can be economically severe; e.g., livestock feed losses through consumption and spillage (Feare and Wadsworth 1981); disease transmission to livestock (Bickford et al. 1966); and damage to crops, such as sunflowers (Avery and DeHaven 1982), grains (Holler et al. 1982, Bollinger and Caslick 1985, Bullard and York 1985), and fruits (Bollinger et al. 1973, Tobin 1985). Birds also accidentally ingest agricultural chemicals such as carbofuran, fensulfothion, and parathion (Balcomb 1983) as nontarget species; their use of these chemicals may restrict man's use of pesticides in some situations.

Efforts to control problem birds include trapping and the use of frightening or lethal chemical agents (Besser et al. 1967, Levingston 1967, West et al. 1967, Feare et al. 1981). These approaches are expensive (Cunningham et al. 1979, Glahn 1981) and fail to create a suboptimal environment for avian feeding activity. Birds often return when control measures are relaxed (Twedt and Glahn 1982).

An alternative or supplement to existing control strategies may be the use of flavor chemicals that are selectively repellent to birds. These flavors could be sprayed on crops, or added to livestock feeds or granulated pesticides to prevent or reduce ingestion. One candidate compound is DMA, a human food flavoring that is palatable to livestock (R. Fisher, U.S. Dep. Agric. and J. R. Mason, unpubl. data), but aversive to starlings (Mason et al. 1983, 1985), red-winged blackbirds (*Agelaius phoeniceus*), Japanese quail (*Coturnix japonica*), pigeons (*Columba livia*), jungle fowl (*Gallus gallus*), herring gulls (*Larus argentatus*) (Kare and Mason 1985), ring-necked

[1] Present address: Monell Chemical Senses Center, 3500 Market Street, Philadelphia, PA 19104-3308.

Table 1. Available physicochemical parameters of 9 anthranilate derivatives examined as repellents of European starlings in experiments 1 and 2.

Experiment and derivative	MW[a]	BP	No. C	% O	% N	% NAC
Experiment 1						
Methyl ($C_8H_9NO_2$)	151.2	256	8	21.1	9.3	15.9
Methyl-N-methyl ($C_9H_{11}NO_2$)	165.1	255	9	19.4	8.5	21.8
Ethyl ($C_9H_{11}NO_2$)	165.2	268	9	19.0	8.5	21.8
Isobutyl ($C_{11}H_{15}NO_2$)	193.2	270	11	16.5	7.3	31.1
Isobutyl methyl ($C_{12}H_{17}NO_2$)	207.0	200	12	15.5	6.8	34.8
Experiment 2						
Isobutyl-N-N-dimethyl ($C_{13}H_{19}NO_2$)	221.2	250	13	14.5	6.1	38.0
Linalyl ($C_{17}H_{23}NO_2$)	259.0	330	17	12.3	5.4	46.3
Phenyl ethyl ($C_{15}H_{15}NO_2$)	241.0	325	15	13.3	5.8	44.8
Propionyl methyl ($C_{11}H_{13}NO_3$)	193.0	178	11	24.9	7.3	31.1

[a] MW = molecular wt, BP = boiling point (C), C = carbon atoms, O = oxygen, N = nitrogen, NAC = nonanthranilate carbons.

pheasants (*Phasianus colchicus*), mallard ducks (*Anas platyrhyncous*) (Bean and Mason 1987), and Canada geese (*Branta canadensis*) (Mason and Clark 1987).

Casual observations suggest that DMA repellency is based on odor (J. R. Mason, unpubl. data). Odor perception by birds is mediated by olfaction (Bang and Wenzel 1985, Wenzel 1985) and nasal trigeminal chemoreception (Mason and Silver 1983, Kare and Mason 1985, Clark and Mason 1987). The former is commonly described as the sense of smell; the latter is part of the common chemical sense (Parker 1912), a system designed to prevent exposure to irritants. Stimulation of trigeminal chemoreceptors leads to a wide variety of protective physiologic reflexes (Jones 1954, Szolcsanyi et al. 1986).

Our experiments were performed to investigate the physicochemical basis for the repellency of DMA and other anthranilate derivatives to birds, and to identify the sensory systems that are used for anthranilate detection. Because odor appeared important, our studies focused on physicochemical parameters controlling volatility, and on nasal chemoreceptor systems.

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METHODS

We decoytrapped or mistnetted 100 adult European starlings during March 1986 and transported them to the Monell Chemical Senses Center, Philadelphia, Pennsylvania. The starlings were individually caged (61 × 36 × 41 cm) under a 6:18 hour, light:dark cycle that maximized feeding, without reducing the total quantity of food consumed (Mason et al. 1983). Water was available ad libitum, and before experiments began, the birds were permitted free access to Purina Flight Bird Conditioner (PFBC) (Purina Mills Inc., St. Louis, Mo.) and crushed shell grit.

One week prior to each experiment, birds were adapted to a food deprivation regime. Deprivation involved removing PFBC and grit from the cages just before dark. Within 30 minutes of light on the next day, each bird was presented with 2 cups (preceding 2-choice tests) or 1 cup (preceding 1-choice tests), each containing 20 g of PFBC. We measured consumption after 2 hours. Birds were then left undisturbed with free access to PFBC and grit for the remaining hours of light. The 2-hour feeding trial procedure, followed by 4 hours free access to PFBC and then overnight food deprivation, was used in all experiments.

Results of each experiment were assessed by analysis of variance (ANOVA). Tukey HSD tests (Winer 1962) were used to isolate significant ($P < 0.05$) differences among means.

Experiment 1: 2-Choice Tests

We selected ethyl, isobutyl, isobutyl methyl, methyl, and DMA anthranilate (Inter. Flavors and Fragrances, Union Beach, N.J.) (Table 1) to examine as repellents (as were the derivatives tested in exp. 2) because data were available

concerning their physicochemical attributes. Based on work by Mason et al. (1983), each derivative was mixed with PFBC to produce flavor concentrations of 1.0% weight-weight (w/w).

We gave 20 randomly chosen starlings 2-choice preference tests between anthranilate and plain PFBC on each of 5 consecutive days. Each bird was offered each anthranilate, but in different randomly selected orders.

A 2-way repeated measures ANOVA (anthranilates and food cups) was used to assess results. Also, molecular weights and boiling points of the anthranilates were ranked, and Spearman's rank-order correlation coefficients were calculated between these rankings and ranked behavioral suppression scores (i.e., consumption of anthranilate PFBC divided by total consumption).

Experiment 2: 2-Choice Tests

We obtained dimethyl, linalyl, phenyl ethyl, propionyl methyl, and isobutyl-N-N-dimethyl anthranilate from Firmenich, Princeton, New Jersey (Table 1). These derivatives were mixed with PFBC to produce anthranilate concentrations of 1.0% w/w.

We gave 20 randomly chosen starlings 5 consecutive 2-choice preference tests. A 2-way repeated measures ANOVA (anthranilates and food cups) was used to assess results.

As in experiment 1, we calculated a rank-order correlation coefficient to associate behavioral suppression scores with physical properties of the derivatives. For this purpose, 6 properties (all reflecting volatility) of each of the 9 derivatives tested in experiments 1 and 2 were considered: molecular weight, boiling point, number of carbon atoms, percent oxygen, percent nitrogen, and percent nonanthranilate carbons. Because these descriptors were confounded, a factor analysis was used to reduce the number of variables (dimensions). The factor scores (Norusis 1986:B41–B69) generated by the analysis were correlated with ranked suppression scores representing the responses of birds in experiments 1 and 2.

Experiment 3: 1-Choice Tests

We mixed the 9 anthranilate derivatives with PFBC to produce 8 flavor concentrations w/w: 1.6, 1.4, 1.2, 1.0, 0.8, 0.6, 0.4, and 0.2%. In addition, we used plain PFBC to obtain a measure of baseline consumption. This range of concentrations was identical to that in a previous evaluation of DMA alone (Mason et al. 1983).

We randomly selected 36 starlings from the 40 birds used in experiments 1 and 2. Following readaptation to the food deprivation regime, the birds were assigned to 9 groups on the basis of consumption; i.e., birds with the highest mean consumption were assigned to the first group, those with the second highest to the second group, and so forth.

Experienced birds were used because retesting allowed comparisons between the performance of the same birds in 1- and 2-choice settings. Also, repeated testing indicated the aversiveness of the anthranilate derivatives over time. Although Mason et al. (1983) had demonstrated that avoidance of DMA does not change, even when birds are given 60 days of experience with the compound, the same might not be true of the other derivatives.

Each group was presented with 1 anthranilate. During 18 days (1 trial/day), we randomly presented each of the 9 flavor concentrations (0.0–1.6%) twice. Mean consumption of each anthranilate concentration by each bird was calculated, and these data were assessed in a 2-way between-within ANOVA (anthranilates and concentrations). We also used mean avoidance thresholds (arbitrarily defined as the midpoint of the greatest decrease in mean consumption, as derivative concentrations increased) in a regression analysis with the factor scores generated in experiment 2.

Experiment 4: 2-Choice Tests Following Olfactory Nerve Cuts

Twenty starlings were given bilateral olfactory nerve cuts (BONC) according to standard procedures (Mason and Silver 1983, Clark and Mason 1987). Sham surgeries were not performed because prior control experiments had indicated that sham birds respond to DMA in the same fashion that intact (unoperated) birds do. These findings are consistent with the responses of sham and unoperated starlings to other odorants (e.g., phenethyl alcohol) (Mason and Silver 1983).

For the BONC procedure, birds were anesthetized by intraperitoneal injection of equithesin (2 mL/kg body wt), and then placed in a specially designed head-holder. The 2 olfactory nerves underlying the bony orbital walls

were exposed, lifted slightly, and a 1-mm section was removed from each. The cut ends of the nerves were folded back to hinder regeneration, the cavity was packed with gelfoam, and the skin was closed with cyanoacrylate glue.

All birds recovered from anesthesia within 1 hour of equithesin injection. During the 5 days following surgery, the birds were adapted to food deprivation. For 9 days thereafter, all birds were given 2-hour 2-choice tests between plain and 1.0% w/w anthranilate PFBC. A different randomly selected order of the derivatives was offered to each bird. We used a 2-way repeated measures ANOVA (anthranilates and food cups) to assess results.

Experiment 5: 1-Choice Tests Following Olfactory Nerve Cuts

We selected dimethyl, isobutyl-N-N-dimethyl, methyl, and linalyl anthranilate as stimuli. We selected these derivatives because of differences in their aversiveness to intact birds. Each derivative was mixed with PFBC to produce 8 concentrations, ranging from 0.2 to 1.6% w/w. As in experiment 3, plain PFBC was used as a control.

The 20 starlings tested in experiment 4 were readapted to food deprivation, and then assigned to 4 groups (n = 5/group) on the basis of consumption. Each group was presented with 1 anthranilate. During 18 days, each of the 9 flavor concentrations was randomly offered twice. Mean consumption of each anthranilate concentration by each bird was calculated, and these values were assessed in a 2-way between-within ANOVA (anthranilate and concentrations).

Experiment 6: 2-Choice Tests Following Trigeminal Nerve Cuts

Dimethyl, isobutyl-N-N-dimethyl, methyl, and linalyl anthranilate (1.0% w/w in PFBC) again served as stimuli. Twenty starlings were given BONC and trigeminal nerve cuts (BTNC). For surgery, each was anesthetized by intraperitoneal injection of equithesin (2 mL/kg body wt), and placed in the head-holder. The olfactory nerves were severed as previously described. Next, the 2 ophthalmic branches of the ethmoid trigeminal nerve (lying directly below where the olfactory nerves had been) were exposed, lifted slightly, and a 1-mm section was removed. These branches are the primary trigeminal innervation of the nasal cavity (Walker et al. 1986). The cut ends of the nerve were folded back, the cavity was repacked with gelfoam, and the skin closed with cyanoacrylate glue. All birds recovered from anesthesia within 1 hour. During the 5 days following surgery, the birds were adapted to food deprivation. For 4 days thereafter, each was given 2-choice tests between flavored and plain PFBC. A 2-way repeated measures ANOVA (anthranilates and food cups) was used to assess results.

Experiment 7: 1-Choice Tests Following Trigeminal Nerve Cuts

Dimethyl, isobutyl-N-N-dimethyl, methyl, and linalyl anthranilate served as stimuli. The 20 BONC and BTNC birds were readapted to food deprivation, and then assigned to 4 groups (n = 5/group) on the basis of consumption. Groups were given 1-choice concentration-response tests, as previously described, among concentrations ranging from 0.8 to 1.6% w/w. As in experiments 3 and 5, plain PFBC was presented as a control. Mean consumption of each anthranilate concentration by each bird was calculated, and these data were assessed in a 2-way between-within ANOVA (anthranilates and concentrations).

RESULTS

Experiment 1: 2-Choice Tests (Intact Birds)

There were no differences among anthranilates (F = 1.0; 4, 76 df; $P > 0.25$), but consumption of plain PFBC was higher than consumption of anthranilate PFBC (F = 86.8; 1, 19 df; $P < 0.00001$) (Fig. 1). The interaction between anthranilates and cups was not significant (F = 1.8; 4, 76 df; $P > 0.10$). Molecular weight (r = 0.80) and boiling point (r = 0.10) were not significantly correlated with behavioral suppression ($P > 0.05$).

Experiment 2: 2-Choice Tests (Intact Birds)

There were no significant differences among anthranilates (F = 0.7; 4, 76 df; $P > 0.25$). However, consumption of plain PFBC was higher than consumption of anthranilate PFBC (F = 241.2; 1, 19 df; $P < 0.00001$) (Fig. 2).

Inspection of the significant interaction between anthranilates and cups (F = 6.9; 4, 76 df; $P < 0.00002$) revealed that consumption of DMA, isobutyl-N-N-dimethyl, linalyl, and propionyl methyl anthranilate were lower than that

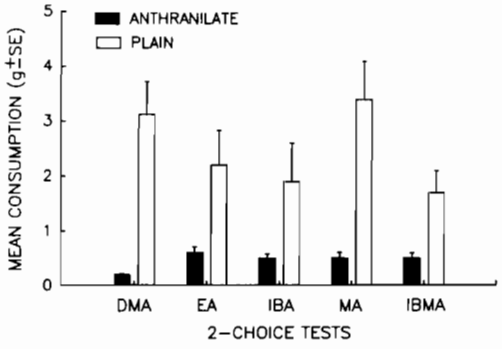

Fig. 1. Two-choice consumption by European starlings in experiment 1. Dark bars represent consumption of anthranilate Purina Flight Bird Conditioner (PFBC). Open bars represent consumption of plain PFBC. Capped vertical lines represent standard errors of the means. DMA = methyl-N-methyl anthranilate, EA = ethyl anthranilate, IBA = isobutyl anthranilate, MA = methyl anthranilate, IBMA = isobutyl methyl anthranilate.

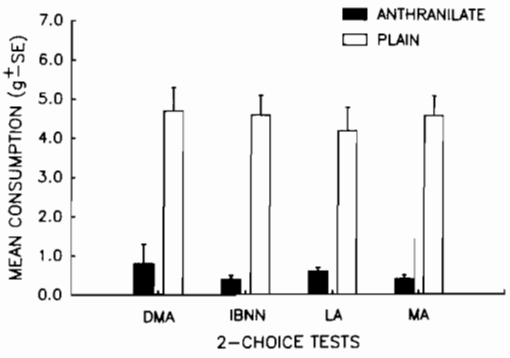

Fig. 2. Two-choice consumption by European starlings in experiment 2. Dark bars represent consumption of anthranilate Purina Flight Bird Conditioner (PFBC). Open bars represent consumption of plain PFBC. Capped vertical lines represent standard errors of the means. DMA = methyl-N-methyl anthranilate, IBNN = isobutyl-N-N-dimethyl anthranilate, PMA = propionyl methyl anthranilate, LA = linalyl anthranilate, PEA = phenyl ethyl anthranilate.

of phenyl ethyl anthranilate. Consumption of plain PFBC was not significantly different among 2-choice tests.

Bartlett's test for sphericity showed that principal components analysis of the physicochemical attributes of the anthranilate derivatives was appropriate (BTS = 30.5, $P = 0.01$). Inspection of the anti-image covariance matrix and the Kaiser-Meyer-Olkin measure of sampling adequacy (0.730) was consistent with this interpretation (Lindeman et al. 1980).

Only 1 factor emerged to explain a significant portion (65.9%) of the variance among the original 6 variables, with an eigenvalue of 3.95. Inspection of the communalities and the factor matrix (Table 2) indicated that the 9 derivatives could be separated along a carbon–oxygen and nitrogen axis. Specifically, derivatives with large factor scores had more carbon atoms and smaller percentages of oxygen and nitrogen. These characteristics reflect volatility. When suppression scores were plotted against this axis, however, no significant relationship was obtained ($r = 0.03$, $P > 0.25$).

Experiment 3: 1-Choice Tests (Intact Birds)

There were significant differences among anthranilates ($F = 7.9$; 8, 27 df; $P < 0.0001$). Dimethyl, methyl, isobutyl, ethyl, and isobutyl methyl anthranilate were significantly more aversive than isobutyl-N-N-dimethyl, linalyl, propionyl methyl, and phenyl ethyl anthranilate. Also, there were significant differences among concentrations ($F = 113.7$; 8, 216 df; $P < 0.00001$); consumption decreased as concentration increased. Inspection of the significant interaction between anthranilates and concentrations ($F = 3.7$; 64, 216 df; $P < 0.00001$) revealed that consumption of phenyl ethyl anthranilate was high at all concentrations (except 0.0%) relative to the other derivatives. At mid-range concentrations, consumption of isobutyl-N-N-dimethyl anthranilate was significantly higher than consumption of the other derivatives, except for consumption of phenyl ethyl anthranilate (Fig. 3).

Avoidance thresholds for all derivatives except phenyl ethyl and isobutyl-N-N-dimethyl anthranilate were between 0.2–0.4% (Fig. 3). For these latter compounds, avoidance thresholds were approximately 1.4 and 0.6%, respectively. When avoidance thresholds were plotted against the carbon–oxygen and nitrogen axis generated in experiment 2, a significant regres-

Table 2. Communalities and factor matrix generated from principal components analysis of anthranilate properties.

Variable[a]	Communality	Factor matrix	Score coefficient
MW	0.125	−0.354	−0.089
BP	0.327	0.572	0.145
No. C	0.974	0.987	0.250
% O	0.606	−0.778	−0.197
% N	0.953	−0.976	−0.247
% NAC	0.970	0.985	0.249

[a] MW = molecular wt, BP = boiling point (C), C = carbon atoms, O = oxygen, N = nitrogen, NAC = nonanthranilate carbons.

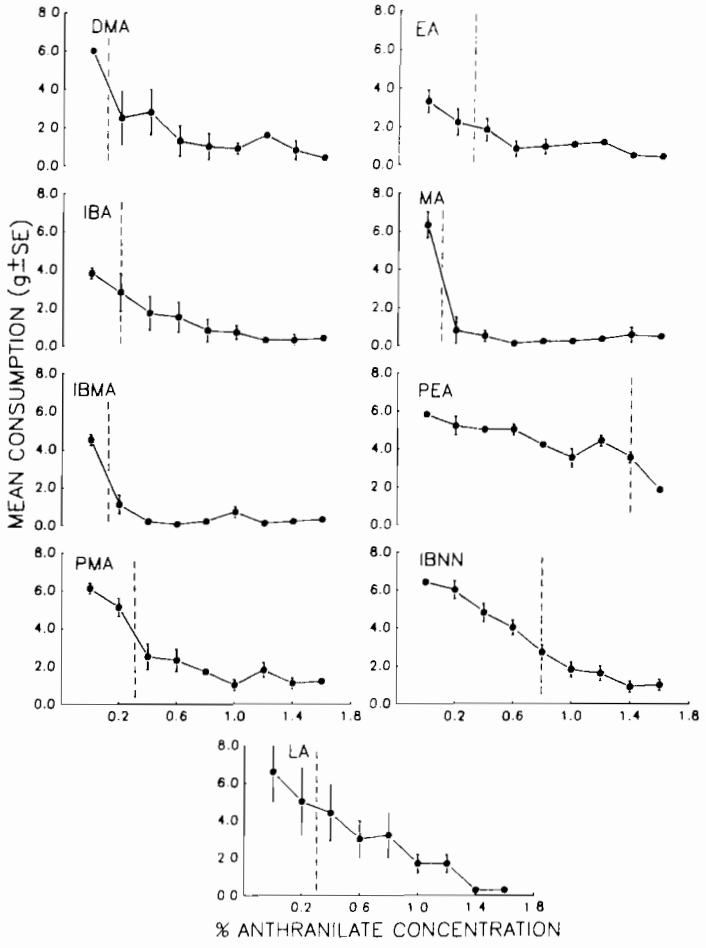

Fig. 3. One-choice consumption by European starlings in experiment 3. Anthranilate concentrations ranged from zero to 1.6% in Purina Flight Bird Conditioner (PFBC). The vertical dotted lines denote avoidance thresholds. Capped vertical lines through points represent standard errors of the means. DMA = methyl-N-methyl anthranilate, IBA = isobutyl anthranilate, IBMA = isobutyl methyl anthranilate, PMA = propionyl methyl anthranilate, LA = linalyl anthranilate, EA = ethyl anthranilate, MA = methyl anthranilate, PEA = phenyl ethyl anthranilate, IBNN = isobutyl-N-N-dimethyl anthranilate.

sion was obtained. Anthranilate derivatives with relatively high volatility (large factor scores) were more aversive than derivatives with low volatility ($r = 0.73$; $P < 0.025$; slope = 0.034 ± 0.012 [SE], intercept = -0.55 ± 0.32).

Experiment 4: 2-Choice Tests Following BONC

As for intact birds (exp. 1 and 2), there were no differences exhibited by BONC starlings among anthranilates in 2-choice tests ($F = 0.7$; 8, 152 df; $P > 0.25$). However, consumption of plain PFBC was greater than consumption of anthranilate PFBC ($F = 351.8$; 1, 19 df; $P < 0.00001$). Inspection of the 2-way interaction ($F = 2.7$; 8, 152 df; $P < 0.007$) showed that while there were no differences in consumption of plain PFBC among tests, consumption of phenyl ethyl anthranilate was significantly higher than consumption of the other derivatives (Fig. 4).

Experiment 5: 1-Choice Tests Following BONC

There were no differences among anthranilates ($F = 1.0$; 3, 12 df; $P > 0.40$). However, post hoc examination of a significant difference among concentrations ($F = 106.0$; 8, 96 df; $P < 0.00001$) showed that consumption decreased as concentration increased (Fig. 5). While the interaction between anthranilates and concentra-

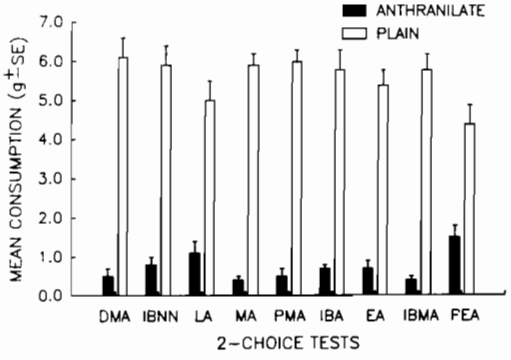

Fig. 4. Two-choice consumption by European starlings after bilateral olfactory nerve cuts in experiment 4. Dark bars represent consumption of anthranilate Purina Flight Bird Conditioner (PFBC). Open bars represent consumption of plain PFBC. Capped vertical lines represent standard errors of the means. DMA = methyl-N-methyl anthranilate, IBNN = isobutyl-N-N-dimethyl anthranilate, LA = linalyl anthranilate, MA = methyl anthranilate, PMA = propionyl methyl anthranilate, IBA = isobutyl anthranilate, EA = ethyl anthranilate, IBMA = isobutyl methyl anthranilate, PEA = phenyl ethyl anthranilate.

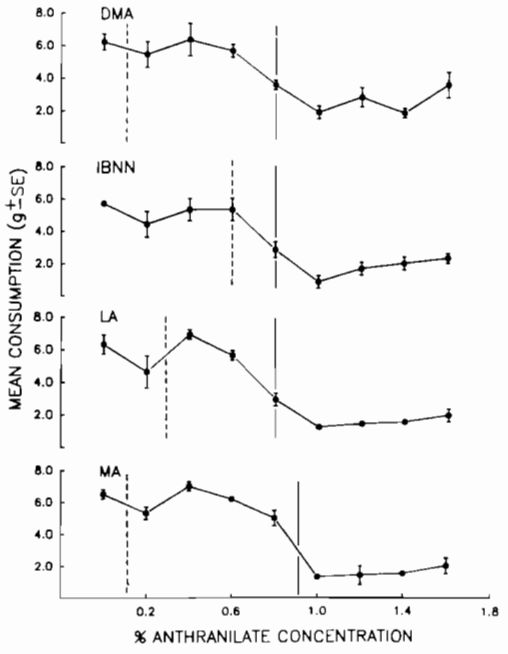

Fig. 5. One-choice consumption by European starlings with bilateral olfactory nerve cuts (BONC) in experiment 5. Anthranilate concentrations ranged from zero to 1.6% in Purina Flight Bird Conditioner. The vertical dotted lines indicate avoidance thresholds of intact birds (exp. 3), while the solid vertical lines indicate BONC avoidance thresholds. Capped vertical lines through points represent standard errors of the means. DMA = methyl-N-methyl anthranilate, IBNN = isobutyl-N-N-dimethyl anthranilate, LA = linalyl anthranilate, MA = methyl anthranilate.

tions was significant ($F = 1.6$; 24, 96 df; $P < 0.05$) post hoc tests failed to isolate any differences among the means.

The greatest increase in repellency (i.e., decrease in consumption) occurred for all derivatives between 0.6 and 1.0% (Fig. 5). The midpoint of this increase (the avoidance threshold) was 0.8%. Relative to the avoidance thresholds obtained in experiment 3, this represented an increase of about 0.5% w/w.

Experiment 6: 2-Choice Tests Following BONC and BTNC

As for intact birds (exp. 1 and 2) and BONC birds (exp. 4), there were no differences among anthranilates ($F = 0.4$; 3, 57 df; $P > 0.50$), and consumption of anthranilate PFBC was lower than consumption of plain PFBC ($F = 91.5$; 1, 19 df; $P < 0.00001$) (Fig. 6). The interaction between anthranilates and cups was not significant ($F = 0.3$; 3, 57 df; $P > 0.50$).

Experiment 7: 1-Choice Tests Following BONC and BTNC

There were no differences among anthranilates ($F = 0.01$; 3, 12 df; $P > 0.50$), but there were significant differences among concentrations ($F = 9.2$; 5, 60 df; $P < 0.00001$). Unlike previous 1-choice tests (exp. 3 and 5), all anthranilate concentrations (0.8–1.6%) elicited greater consumption than plain PFBC (Fig. 7). No avoidance thresholds could be discerned. The interaction between anthranilates and concentrations was not significant ($F = 0.4$; 15, 60 df; $P > 0.50$).

DISCUSSION

In 2-choice tests with intact birds, all of the anthranilate derivatives (with the exception of phenyl ethyl anthranilate) were aversive. Moreover, in 1-choice tests with intact birds, methyl, isobutyl, ethyl, and isobutyl methyl anthranilate were as aversive as DMA.

When the olfactory nerves were cut, a similar pattern of results was obtained. However, avoidance thresholds increased from a mean of 0.3–0.8%, suggesting that olfaction was partly responsible for avoidance.

When the trigeminal nerves were cut, birds continued to avoid anthranilate derivatives in 2-choice tests, suggesting that taste or perhaps trigeminal innervation of the oral cavity or eyes continued to mediate detection. However, the

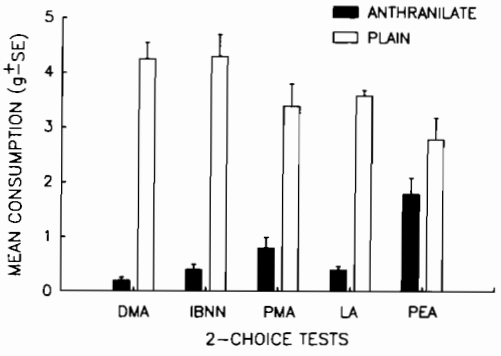

Fig. 6. Two-choice consumption by European starlings with bilateral olfactory and nasal trigeminal nerve cuts in experiment 6. Dark bars represent consumption of anthranilate Purina Flight Bird Conditioner (PFBC). Open bars represent consumption of plain PFBC. Capped vertical lines represent standard errors of the means. DMA = methyl-N-methyl anthranilate, IBNN = isobutyl-N-N-dimethyl anthranilate, LA = linalyl anthranilate, MA = methyl anthranilate.

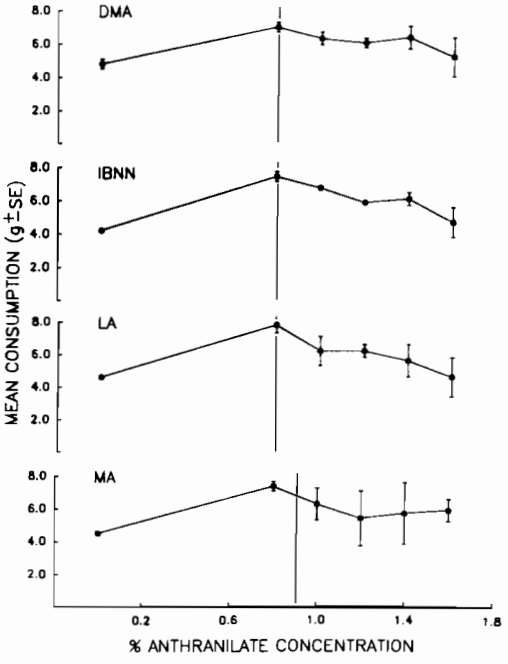

Fig. 7. One-choice consumption by starlings with bilateral olfactory and nasal trigeminal nerve cuts in experiment 7. Anthranilate concentrations ranged from 0.8 to 1.6% in Purina Flight Bird Conditioner (PFBC), and plain PFBC was presented as a control. The vertical lines indicate avoidance thresholds of birds following bilateral olfactory nerve cuts (exp. 5). Capped vertical lines through points represent standard errors of the means. DMA = methyl-N-methyl anthranilate, IBNN = isobutyl-N-N-dimethyl anthranilate, LA = linalyl anthranilate, MA = methyl anthranilate.

lack of avoidance of anthranilates in 1-choice tests suggests that nasal trigeminal chemoreception may have been more important than olfaction for avoidance responding.

Together, the results of all experiments suggest that the volatility of anthranilate derivatives is a critical feature of their detection and avoidance by starlings. This interpretation is supported by the results of the rank-order correlation in experiment 3 between factor analysis scores and consumption. Scores for derivatives with few carbons and large percentages of oxygen and nitrogen (i.e., relatively more volatile anthranilates) were positively and significantly correlated with behavioral suppression (avoidance). However, because no significant correlations were obtained in experiments 1 and 2, and because the significant principal component in experiment 2 explained only 66% of the variance among physicochemical parameters, more detailed information about the character of the derivatives must be obtained before meaningful conclusions can be drawn regarding structure–function relationships.

Although previous work has indicated that starlings do not habituate to the aversive characteristics of DMA (Mason et al. 1983), the possibility remains that apparent reductions in sensitivity in 1-choice tests were in part the result of prior 2-choice test experience. Additional testing with naive birds is required to address this issue.

MANAGEMENT IMPLICATIONS

Our results confirm previous laboratory and field demonstrations of DMA efficacy as a bird repellent, and suggest that methyl, isobutyl, ethyl, and isobutyl methyl anthranilate are aversive to birds. From an economic point of view, these findings are important, because methyl anthranilate is 4–5× less expensive than DMA (R. Trksak, Natl. Starch and Chem. Co., Bridgewater, N.J., pers. commun.). We speculate that any of these 4 anthranilates may be useful for bird control. Aversiveness is based at least in part on odor characteristics, rather than on taste, and it follows that anthranilate avoidance may not depend on contact between a bird and a treated food (i.e., in some situations, anthranilate odor could repel birds prior to the ingestion of any treated material). If so, then anthranilates might be used to reduce nontarget hazards associated with toxic agricultural chemicals (e.g., carbofuran, fensulfothion, parathion).

An important caution is that anthranilates are unlikely to act as effective repellents in all situations with all avian pests. As suggested by Rogers (1978), differences in the materials to be protected from damage will influence the efficacy of control practices. Highly preferred foods and sole food sources will be more difficult to protect, and the relative palatability of alternative foods will influence the repellency of anthranilate treated foods. Comparison of 1- and 2-choice tests in the present experiments can be used to illustrate these points. All 9 anthranilates were aversive when alternative untreated PFBC was available. In 1-choice tests, however, only DMA, methyl, ethyl, isobutyl, and isobutyl methyl anthranilate were aversive. Clearly, the test procedures used to evaluate a candidate repellent will influence whether the compound is accepted for further testing or rejected.

Even when anthranilates are not totally effective, they may serve as useful components of integrated pest management strategies. Anthranilate treatments of livestock feed might be used in combination with Starlicide (Purina Mills, St. Louis, Mo.) applications at bait stations in feedlots. By decreasing the palatability of livestock feeds with an anthranilate, it is conceivable that the palatability and/or attractiveness of alternative foods (i.e., Starlicide baits) would increase. This increase would lead to greater efficacy of the Starlicide, perhaps with less effort expended in prebaiting (Stickley 1979). Further testing of anthranilate derivatives for reducing bird depredations and nontarget hazards associated with toxic agricultural chemicals appears warranted.

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